The Angiotensin-Converting Enzyme Inhibitor ‘Enalapril’ Increases the Anti-Proliferative Activity of 5-Fluorouracil in Colorectal Cancer Cells

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Abstract

The dysregulation of angiotensin-converting enzyme inhibitor (ACE-I) and its pathway has been reported to be associated with oncogenesis and poor prognosis in colorectal cancer (CRC). We explored the therapeutic potential of targeting ACE-I through the use of enalapril and investigated its pharmacological interaction with 5-FU in CT26, HT29, and SW480 cells. The anti-proliferative and anti-migratory effects as well as apoptotic activity of this agent on cell cycle have been evaluated by MTT, wound healing assay, and FACS, while the expression of genes was determined through mRNA or protein levels. According to the observations, enalapril has inhibited cell proliferation in a dose-dependent manner and affected the anti-tumor properties of 5-FU via increasing the levels of apoptosis and ROS, as well as through the modulation of antioxidant/oxidant markers. Enalapril has also suppressed cell migration by the perturbation of MMP-3/MMP-9 and E-cadherin. The combination of enalapril and 5FU has resulted in decrease in the expression levels of ACE, AT1R, and SMAD-3. Our findings suggested that targeting ACE-I by applying the modulation of angiotensin pathway could increase the activity of 5-FU due to interfering with cell-proliferation, apoptosis, and inflammatory markers, which is indicative of its potential value as a therapeutic option for the treatment of CRC.

Keywords: ACE inhibitor, Enalapril, Colorectal Cancer, Combination therapy

Cancer is typically distinguished by detecting its progressive and degenerative effects. It can also be characterized by abnormal control mechanisms that affect cell survival, proliferation, and differentiation.[1] Colorectal cancer is one of the important causes of mortality and leads to 500,000 deaths annually worldwide.[2] However, although patients are treated with the combination of different chemotherapy agents, most of them eventually become resistant to the treatments.[3, 4] An angiotensin-converting enzyme inhibitor (ACE-I), Enalapril, is exerted in clinical practice throughout the treatment of several conditions, including hypertension and heart failure.[5] This substance can reduce cell proliferation and cause cell death by inducing cellular signaling pathways that involve TGF-beta as the main regula-
tor and suppressor factor of tumor in epithelial cells.[6] Moreover, enalapril plays a role in cell differentiation, extracellular matrix formation, and immune response.[1, 6] However, the recent evidences have exposed the antitumor effect of ACE and ARB inhibitors in different malignancies.[7, 8] According to available reports, ARB inhibitors can cause a decrease in the VEGF expression and an increase in apoptosis.[9-11] Besides, it has been indicated by tumor sorts and phases that TGF-β signaling has an important and complicated functionality throughout the CRC Progression.[12-14] The lack of Smad4 can cause an increase in VEGF expression within the CRC cells. [15] However, a high expression rate of VEGF can be related to an extreme vascular solidity, expansion of metastasis, and resistance to medicines, leading to a worse prognosis in CRC.[16] Several articles have suggested that ACE-I can decrease tumor extension and metastasis.[17] In addition, it has been reported that TGF-beta receptor is regulated by these inhibitors.[8] Angiotensin-2 is capable of enhancing the extension of numerous tissues, including liver, kidney, lung, and heart,[7] and advancing its functionality in regards to other cell growth factors.[9] In this study, we evaluated the anti-tumor effects of enalapril and 5-FU combination for the purpose of investigating the cellular and molecular pathways that are involved in colorectal cancer cells.

**Methods**

**Chemicals and Drugs**

Enalapril was provided from Huahaipharm in China, and dissolved in methanol. 5-Fluorouracil (5-FU) was obtained from ebewe PHARMA Ges (Unterach, Austria) and dissolved in distilled water, and we purchased RPMI-1640 medium, Fetal Bovine Serum (FBS), penicillin/streptomycin (pen-strap; 50 μg/mL) from in vitro gene (Gaithersburg, MD).

**Cell Culture**

The required colorectal cancer cells CT26, HT29, and SW480 were obtained from Pasteur Institute and were incubated in the RPMI-medium and DMEM-medium that contained 10 % FBS and 1% pen-strap, which were then maintained at 37 °C and 5 % CO₂.

**Growth Inhibition Studies**

The cytotoxic activity of drugs was evaluated by the means of MTT assay. Briefly, we plated the cells (2×10⁶) in 96-wells and treated them with different concentrations of enalapril, 5-FU, and enalapril+5-FU combination (1mM, 500μM, 300μM, 100μM, 10μM, 500nM, 100nM, 50nM, 10nM) for 72 h. Then, the plate was read at 570 nm through the use of an epoch spectrophotometer[11] and the value of IC₅₀ was examined by Prism software.

**Multicellular Spheroids**

The cytotoxic activity of utilized drug was assessed in a 3-D cell culture model of CT26 cells. For this purpose, we generated the spheroids by plating 10⁶ cells/mL in agarose coated 96-well plates and performed a thorough examination under microscope. The volume of spheroid (V) was determined by the following formula: $V = \frac{4}{3} \pi \left(\frac{D}{2}\right)^3$ (1)

**Migration Assays**

The ability of enalapril, 5-FU, and enalapril+5-FU in suppressing the migratory was investigated by the use of starch assay. A monolayer of CT-26 cells was scratched with a pipette. 24h later, the required images were taken at different time intervals as follows; 12, 24, 36, 48, and 72h.

**Quantitative RT-PCR**

Initially, RNAs were extracted from the cells that were treated with enalapril at IC₅₀ through the utilization of RNXPL (CinaColon, Tehran, Iran). Once the cDNA was synthesized (CinaColon, Tehran, Iran), we amplified it with specific primers for ACE, AT1-R, TGF-beta1, VEGF A, Smad3, and MMP-3 and MMP-9 genes (Macrogen Co, Seoul, Korea) by exerting the ABI StepOne instrument (Applied Biosystems, Foster City, CA). The 2-ΔΔCT method was extensively used as a relative quantification strategy for quantitative real-time polymerase chain reaction (qPCR) data analysis. The housekeeping gene GABDH were used.

**Apoptosis Analyses**

Annexin-V–fluorescein isothiocyanate (FITC) and propidium iodide (PI) assay kits (Cayman chemical Co, Michigan) were used to assess apoptotic cell death. Briefly, the cells of CRC were distributed at a density of 2×10⁶ cells per well in 6-well plates, and treated with enalapril, 5FU and combination of enalapril and 5FU for 48 hr. The cells extracts were suspended in 200 μL 1X Annexin V binding buffer. After centrifuging cells (for 5 minutes at 400 g), the cell pellets were re-suspended in Annexin V-FITC/PI staining solution and were incubated at room temperature for 15 minutes. Subsequently, the rate of viable, secondary necrotic cells, early and late apoptotic cells was quantified using FACS-Calibur flow cytometer (BD Biosciences-US) and FlowJo software.

**DAPI Staining**

DAPI (4’, 6-diamidino-2-phenylindole dihydrochloride) staining was used to assess the morphology of nuclei.
1.5×10^5 cells. To perform this procedure, the cells were plated in 6-well plate and treated with enalapril, 5-FU, and enalapril+5-FU combination, which were then incubated for 48h. Thereafter, we washed them with PBS and append- ed DAPI to have the cells incubated for 10 min. After another step of washing, the cells were suspended in 1000 μL of ethanol to observe the nuclei morphology under fluorescence microscopy (Olympus, Japan).

**Caspase-3 and -9 Activity**

We exerted a Bio Assay Kit (Abcam-UK) to assess the Caspase -3/9 activity. In this process, 3×10^6 cells were treated with the IC_{50} value of drug for 48 h, which were then harvested and mixed with 50 μL of cell lysis buffer. As the next step, 50 μL of reaction buffer plus 10 mM DTT was appended. After being mixed with 5 μL of the substrates (4 mM), it was incubated for 1 h at 37 °C and recorded the absorbance at 405 nm.

**Reactive Oxygen Species (ROS) Evaluation by DCFH-DA Method**

The evaluation of intracellular ROS production was performed by measuring the induced change in the absorbance of redox-sensitive dye 2’, DCFH-DA, and it was converted to a green highly fluorescent product, DCF. Briefly, the CRC cells were treated with enalapril, 5-FU, and enalapril+5-FU combination for 6 h within a complete medium. Then, the cells were incubated in a fresh culture medium that contained DCFH-DA for 30 min. After being washed for three times with PBS, we measured the fluorescence values by the use of a fluorimeter and the images of the cells were taken by an inverted fluorescence microscope.

**Cytokine Detection Assays**

The Quantification of IL-6 and TNF-α in colon cancer cells was performed through the use of cytokine ELISA kits (bio-science), while keeping the process in accordance with the manufacturers’ protocol.

**Measurement of MDA**

We measured the MDA level of the cells that were treated with enalapril, 5-FU, and enalapril+5-FU, which was previously described. Shortly, 1 mL of the 10% homogenates sample was added to 2 mL of TBA+TCA+HCl solution for 45 min and then was centrifuged for 10 min. In the following, the mixture was measured at 535 nm and the level of MDA was calculated by applying the given equation (Eq. 2):

\[
C_{(M)} = \frac{A}{1.65} \times 10^5 \tag{2}
\]

**Assessment of Total Thiol Groups**

The total thiol was evaluated by the application of DTNB. In detail, 1 mL of Tris-EDTA at the pH 8.6 was mixed with the designated samples and read at 412 nm (A1). Then, we have added 20 μL of DTNB to the solution, while continuing the process by incubation for 15 min and recording again as A2. The DTNB absorbance was considered to be blank (B). It should be noted that the level was calculated by (A2 – A1 – B) × (1.07/0.05 × 13.6).

**SOD Activity**

Superoxide dismutase was evaluated by the utilization of Ransod kit (Randox Laboratory, London, UK), and the Enzyme response velocity was evaluated through the conversion of H_2O_2 to H_2O and O_2 as described.

**Statistical Analysis**

The given data was presented as mean±SEM. SPSS-20, while Prism was applied to assess the statistical significance and it was set as p≤0.05.

**Results**

**Enalapril Reduced Cell Growth and the Migratory Behavior of Cells**

According to the assessment of the growth inhibitory effect of enalapril, 5-FU, and enalapril+5-FU combination, it was indicated that an increase in the enalapril concentration could result in a decrease in the cell growth (Fig. 1a). In order to explore whether enalapril was also active in 3D cell models and it was capable of overcoming the major obstacles in conventional methods, we developed spheroids and treated them with enalapril at IC_{50} (235 μg/mL) values. According to the outcomes, enalapril was able to reduce the size of tumor after 8 days, which was exhibited in Figure 1 b-c. Furthermore, we investigated the effects of enalapril on migratory behaviors (Fig. 1d-e). The obtained data revealed a significant reduction in the migration of CRC cells after 20 hours. In the following, the expression level of E-cadherin, MMP-3, and MMP-9 was evaluated (Fig. 1f) and it could be stated that this drug was able to suppress the expression of MMP-3 and MMP-9, while increasing the level of E-cadherin.

**Effects of Enalapril on Increasing Apoptosis**

In this part of our work, we determined the apoptotic activity of enalapril in CRC cells through the DAPI staining, which provided some information on nuclear apoptosis and DNA fragmentation. According to our data, although the treated cells exhibited cell death in higher enalapril concentrations, it was more pronounced in the case of
enalapril plus 5-FU combination (Fig. 2a). Furthermore, the level of caspase activation was calculated by the means of calorimetrically assay (Fig. 2b) and the outcomes suggested that enalapril could exceed the cytotoxic functionality of 5-FU by increasing the caspase3/9 activity in treated cells, as compared with the control group. Also, we found that enalapril, 5-FU, and combination increased in both early (annexin V positive/PI negative) and late (annexin V and PI positive) apoptosis (Fig. 3).

**Figure 1.** Inhibition of cell proliferation and migration in colorectal cancer cells; (a) Growth inhibitory effects after 72 h exposure to enalapril and 5-FU in CRC cells, (b, c) Effect of enalapril and 5-FU on the CT26 cells spheroids, (d, e) Migration of CT26 cells with enalapril and 5-FU, and (f) Modulation of E-cadherin and MMP3/9 mRNA levels in CRC cells after 24 h exposure to enalapril and 5-FU as determined by qRT-PCR. Columns or points, mean values obtained from three independent experiments; Error bars, standard error of the mean. *Significantly different from controls (c).

Enalapril in Combination with 5-FU Increased ROS Generation, Modulate Antioxidant/Oxidant, and Cytokines Factors

Our results indicated that enalapril could increase the generation of ROS in CRC cells, which can be detected through the measurement of DCFH-DA staining (Fig. 4a-b). These outcomes suggested that enalapril could disrupt the antioxidant/oxidant balance and cause more ROS production, resulting in increased damage and consequently leading to a higher number of CRC cell death. To further assess the role of enalapril in oxidative stress, we had to measure the concentrations of SOD, MDA, and thiol (Fig. 5). The level of MDA was increased, while the level of SOD and total thiol were decreased in the CRC cells that were treated with enalapril. Moreover, we explored the effect of enalapril and its combination with 5-FU on expression levels of TNF-α and IL-6. According to the results, the administration of enalapril+5-FU caused a decrease in the expression level of inflammatory cytokines (Fig. 6b), suggesting that this drug could attenuate
Figure 2. The apoptotic activity of agents; (a) DAPI staining displayed DNA fragmentation and nuclear apoptosis and confirmed apoptotic cell death in IC$_{50}$ concentration in CRC treated cells, (b) the level of caspase activity.

Figure 3. Induces apoptosis of CRC cells; CT-26 cells were treated with enalapril for 24 h and apoptosis was explored by flow cytometry using annexin V/PI staining. The values of the lower right and the upper right area indicate the percentage of the cells in early and late apoptosis, respectively.
inflammatory responses by regulating the oxidative stress of CRC cells. It can be concluded that a significant reduction was observed in the levels of ACE, AT1-R, TGF-β, and SMAD3 throughout the cells that were treated with enalapril, which was indicative of the inhibition of ACE/ARB pathway in CRC cells (Fig. 6a).

Figure 4. Modulation of oxidant and antioxidant activities; (a, b) the effects of enalapril and 5-FU on production of cellular ROS were explored in CRC cells (***p<0.001 compared to control group).

Figure 5. Regulatory effects of enalapril and 5-FU on MDA SOD and thiol levels in CRC cells (***p<0.001 compared to control group).
Discussion

The anti-proliferative property of enalapril and its interaction with 5-FU in CRC was demonstrated in this work for the first time. It was indicated by our data that targeting angiotensin II type I pathway could result in inhibition in the cell growth in colorectal cancer, which could be achieved by restraining the TGF-beta pathway and inflammatory markers (Fig. 4d). According to the observations, the functionality of RAS system in cancer is so crucial and significant that the Ang II–AT1R system has recently gained such substantial attention as a therapeutic option in the treatment of different malignancies, including CRC. Ang II is capable of modulating PI3K/Akt pathways. We exhibited in this work that the expression of AT1-R and ACE could be decreased through the application of enalapril, which could also increase the caspase-9/3 activation. Furthermore, Ang II is able to minimize cell adhesion/invasion via type 1 receptor, which is caused by the induced reduction in the expression of integrins. Ang II has been reported to take action through AT1Rs and increases the expression of VEGF, which leads to the occurrence of cell growth, migration, and angiogenesis. Relative observations have stated that the activation of AT1R can perturbate cytokines via MAP kinase, ROS activation, and NF-kB pathways. It has been reported that ACE-I can suppress cell growth and angiogenesis through the RAS-dependent inhibition of Ang II levels. The Intrinsic metal-chelating properties of certain ACE-I could be assumed as the reason behind their anti-cancer functionality, since this substance is responsible for the suppression of MMPs. In addition, ACE-I can directly decrease the plasminogen activator and sulfhydryl group, which leads to the inhibition of angiogenesis. It is also notable that the depletion of ROS could activate MMPs and VEGF.

A few studies have described that ACE-I may actually encourage cell growth due to their immune-modulatory functionality and may increase the rate of kidney cancer. A study on 5027 patients has suggested that ACE-I may be effective in post-anthracycline cardiotoxicity throughout the treatment of pediatric cancer. However, several studies have shown that genetic variant and alteration in ACE and ARB pathways are associated with the increased risk of developing different malignancies, which further points out the significant value of this pathway as a potential target. Our results showed that enalapril or 5-FU alone cannot significantly contribute to the improvement of CRC while the two drugs synergistically exacerbate the
above effects. Because tumor invasion and therapeutic resistance are closely related to EMT, NF-κB/STAT3 and TGF-β signaling are essential for the promotion of EMT in colorectal cancer. We investigated the effect of the combination of two drugs on cell migration and E-cadherin expression and the results showed that the combination of enalapril and 5-FU significantly reduced cell migration. In summary, this work exhibited the therapeutic impact of enalapril and its combination with a standard chemotherapeutic agent (5-FU) in the treatment of CRC for the first time, nevertheless, further in vivo and clinical trial studies are required to explore the value of these strategies for being applied in the treatment of this disease.

Disclosures

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References


